

Nutrient Requirements and Feed Costs Associated with Genetic Improvement in Production of Milk Components

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ABSTRACT

Dietary requirements for NE_L and absorbed true protein were summarized for marginal production of milk components because of genetic improvement through selection. Shelled corn and soybean meal were used to meet marginal nutrient requirements and were assigned variable concentrations of absorbed true protein, depending on rumen-available energy and protein. Mean ratios among national averages for shelled corn to milk prices and soybean meal to milk prices (DM: standardized milk, dollars per kilogram) over a recent 25-yr period were .52 and 1.20, respectively. Stability of these relationships over time permits estimation of feed costs from milk price as prices inflate. Feed costs per kilogram of component, expressed as kilograms of standardized milk with equivalent value, were 1.00 for lactose, 1.89 for fat, and 3.49 for protein. Costs of milk protein were higher if production of absorbed true protein was limited by rumen-available energy, suggesting that selection for fat or lactose, in addition to protein, may be beneficial. High feed costs for milk protein indicate a need for adequate compensation to producers for milk protein and consideration of feed costs during selection. A net value index

is proposed that considers feed costs associated with marginal production of individual milk components.

(Key words: genetic selection, feed costs, milk components, nutrient requirements)

Abbreviation key: AP = absorbed true protein, APE = absorbed true protein supplied by rumen-available energy, APP = absorbed true protein supplied by rumen-available protein, APR = absorbed true protein requirements, ME = metabolizable energy, MPS = microbial protein synthesis, NE_{LR} = NE_L requirements, $PTA\$_p$ = product value index, RUP = rumen-undegraded protein, SBM = soybean meal, SC = shelled corn.

INTRODUCTION

Selection for increased production of milk protein has received much attention (28). More than 87% of cows on DHI programs are tested for milk protein (30), and all active AI sires have PTA for protein production. Norman (27) introduced a product value index ($PTA\$_p$) that included the production of milk, fat, and protein. This index estimates gross economic value of milk from future daughters compared with a genetic base and has become the standard for ranking animals by the USDA Animal Improvement Programs Laboratory.

The effect that protein selection has on economic return to producers is unclear. Several workers have stated that selection should be based on net economic values of the production traits rather than on gross values (1, 15, 23, 28). If the cost of marginal production of milk components as a proportion of market value varies among traits, ranking of animals

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based on net value differs from that based on gross value. Furthermore, net values for production traits would be required if non-production traits were combined with yield traits in selection indexes. Variable costs associated with marginal production include feed, transportation, and processing and, perhaps, health, reproduction, and other management costs (15, 28). Among these, feed cost has the greatest contribution (7), is most highly correlated with profit per day (2), and accounts for >50% of total production costs (4, 9). Energy and protein are the primary nutrients limiting milk production (4, 7, 9) and constitute the largest portion of feed costs associated with genetic gains in milk components (14).

Most studies have estimated only energy costs associated with production of milk components. Hillers et al. (20) calculated metabolizable energy (ME) required for each component using theoretical energy efficiencies developed by Baldwin (3). At energy costs of \$.037/Mcal of ME, they (20) estimated feed costs of \$.244, \$.603, and \$.315/kg of lactose, fat, and protein, respectively. Mbah and Hargrove (23) made similar assumptions but used a cost of \$.058/Mcal of ME. Dommerholt and Wilmink (13) described a selection index based on marginal return that has been used in The Netherlands since 1980. Their energy requirements for each component also were based on calculations of Baldwin (3). Gibson (16) used energy requirements of Dommerholt and Wilmink (13) for each component and an energy cost of \$.0147/MJ of ME, and Keller and Allaire (21) estimated ME requirements based on the NE_L content of each component and a constant efficiency factor. All of these previous cost estimates may be inadequate for use in selection models, however, because they assume static prices for feed energy, fail to account for dietary protein requirements, and may use inappropriate energy requirements (11).

Only one study has considered both dietary energy and protein required for marginal production. Kuipers and Shook (22) calculated net returns from selection under various testing plans and estimated feed costs assuming energy and protein requirements were a function of 4% FCM and milk protein production. Using this model and 1980 feed and milk prices, marginal incomes over feed cost for

lactose and fat production were >80% of their gross value, but net return from milk protein was <20%. Results of Kuipers and Shook (22) indicated that net return from selection was not a constant proportion of gross return for all milk components and that current rankings on PTA_{\$p} index may not be optimal for net return. Although their requirement models were not well founded because of oversimplified efficiency coefficients, the study suggests that consideration of protein requirements may be important.

The overall objective of this study was to estimate feed costs that were associated with genetic improvement in milk lactose, fat, and protein production in the US. To meet this objective, we needed to define the energy and protein requirements for marginal component production, to determine feedstuff quantities needed to supply these nutrients, and to develop a feed cost model for each feed ingredient. A product value index adjusted for feed costs is proposed.

MATERIALS AND METHODS

Nutrient Requirements

Increased genetic merit for production requires additional conversion of absorbed nutrients to milk components. Such conversion may result from greater net efficiencies of nutrient utilization, greater consumption of dietary nutrients, or combinations of both. If responses associated with genetic selection result solely from increases in nutrient utilization, no additional dietary nutrients would be required for marginal production, and no feed costs would be incurred. However, genetic merit for production was assumed to affect only nutrient intake requirements and not net conversion efficiencies (see Discussion for justification).

Requirements for dietary energy and protein were defined independently for milk lactose, fat, and protein. In previous work, Dado et al. (11) derived ME and absorbed true protein (AP) requirements for each milk component using models of biosynthesis, where AP was defined as AA absorbed into the blood from the small intestines (25). Mertens and Dado (24) used these AP requirements but defined energy requirements in terms of the energy

content of each milk component, or NE_L , to balance complete rations for milk production of varying composition. Their model required the use of NE_L because of equations for predicting microbial protein synthesis (MPS) (24, 25). Requirements for NE_L (NE_{LR}) (24) and AP (APR) (11) were used in this study. The chosen model for APR assumed that 10% of glucose needs were met by glucogenic AA; this conversion is within the 8 to 12% range reported by others (33) for dairy cows.

Feed Requirements

Nutrient consumption may be increased one of three ways: increased DMI, increased nutrient density in the diet, or increases in both. Intake has a moderate and positive genetic correlation with milk production (14), but correlations between intake and individual milk components are unknown. Feeds with high concentrations of energy and protein (concentrates) were assumed to provide the nutrients required for marginal production, and their marginal intakes over a complete lactation were assumed to be unlimited. No change in forage consumption as a result of genetic gain was assumed. The ration that supplies nutrients for production at the genetic base was assumed to be balanced for NE_L and AP, to be optimal for MPS, and to be adequate for all maintenance and base lactational requirements without excess nutrients.

Quantities of an energy and protein supplement needed to meet marginal requirements were determined by solving two equations simultaneously:

$$\begin{aligned} NE_{LR} &= NE_e \times E + NE_p \times P \\ APR &= AP_e \times E + AP_p \times P \end{aligned} \quad [1]$$

where

NE_e = energy content (megacalories of NE_L per kilogram of DM) of an energy supplement,

NE_p = energy content (megacalories of NE_L per kilogram of DM) of a protein supplement,

AP_e = protein content (kilograms of AP per kilogram of DM) of an energy supplement, and

AP_p = protein content (kilograms of AP per kilogram of DM) of a protein supplement.

This model is a simplified version of a model for complete ration formulation developed by Mertens and Dado (24). Their model required too many inputs and assumptions for use in deriving feed costs from marginal production.

Shelled corn (SC) and soybean meal (SBM) were used as energy and protein supplements because of their consistent composition, widespread availability, and relatively low and predictable cost. Energy concentrations were SC = 1.96 Mcal of NE_L /kg of DM, and SBM = 1.94 Mcal of NE_L /kg of DM (26). Changes in energy values of feedstuffs because of variation in digestibility when intakes differed from three times maintenance (26) were not made because production at the genetic base [8615 kg of milk for US Holsteins (31)] is met at intakes near three times maintenance for all dairy breeds. Energy values for feeds would decrease approximately 1% for each 1000 kg of milk produced above the genetic base, assuming a 4% reduction in energy values for each multiple of intake above maintenance (26). Relatively small differences exist among cows for energy digestibility across ranges of genetic merit.

Feedstuff AP is a function of its rumen-undegraded protein (RUP) content and MPS potential. Mertens and Dado (24) indicated that SC and SBM contain two MPS potentials, depending on the relative availabilities of energy and protein in the rumen of cows. Consequently, feedstuff AP is the smaller of AP supply when limited by rumen-available energy (APE) and AP supply when limited by rumen-available protein (N) (APP). Under APE, SC and SBM contain .131 and .229 kg of AP/kg of DM, respectively; under APP, SC and SBM contain .078 and .370 kg of AP/kg of DM (24). For this study, a model was required to select the appropriate AP concentration for SC and SBM under various requirement situations.

When SC and SBM were used to meet marginal requirements, a unique NE_{LR} :APR ratio for the sum of all marginal requirements existed when requirements were met exactly and all rumen-available N was trapped by microbes fermenting all rumen-available energy.

This ratio was determined by utilizing two 2×2 matrices, derived from Mertens and Dado (24), each containing the NE_L equation and one of the AP equations for SC and SBM:

$$\begin{matrix} NE_L: \\ APP: \end{matrix} \begin{bmatrix} 1.96 & 1.94 \\ .078 & .370 \end{bmatrix} \begin{bmatrix} SC \\ SBM \end{bmatrix} = \begin{bmatrix} NE_L R \\ APR \end{bmatrix} \quad [2]$$

$$\begin{matrix} NE_L: \\ APE: \end{matrix} \begin{bmatrix} 1.96 & 1.94 \\ .131 & .229 \end{bmatrix} \begin{bmatrix} SC \\ SBM \end{bmatrix} = \begin{bmatrix} NE_L R \\ APR \end{bmatrix} \quad [3]$$

When these two sets of equations were solved to equal solutions, the $NE_L R:APR$ ratio that optimized MPS and AP production was determined:

$$\begin{matrix} APP: \\ APE: \end{matrix} \begin{bmatrix} -.136 & 3.42 \\ -.680 & 10.15 \end{bmatrix} \begin{bmatrix} NE_L R \\ APR \end{bmatrix} = \begin{bmatrix} SBM \\ SBM \end{bmatrix} \quad [4]$$

$$NE_L R:APR = 12.36. \quad [5]$$

Figure 1 illustrates how quantities of AP supplied were equal for Equations [2] and [3] at an $NE_L R:APR$ ratio of 12.36 using SC and SBM. Below 12.36, APE determined MPS and AP supply, and rumen-available N was in excess. Above 12.36, APP determined MPS and AP supply, and rumen-available energy was in excess. Quantities of SC and SBM were determined for all milk components at various $NE_L R:APR$ ratios.

Feed Costs

Historic relationships of feed and milk prices in the US were evaluated to express feed costs in terms of the amount of standardized milk (3.5% fat and 3.2% protein) having equivalent value. Such an expression allows a long-term relationship of feed costs to be determined and accounts for changes in prices because of inflation. Feed:milk price ratios and regression of feed price on milk price were determined. Average feed and milk prices across the US from 1964 to 1988 were obtained from the USDA, Statistical Reporting Service (Steve Wilson, 1989, personal communication). Corn prices were 120% of the price received by producers, representing an unspecified blend of values for corn produced on the farm and for corn purchased commercially

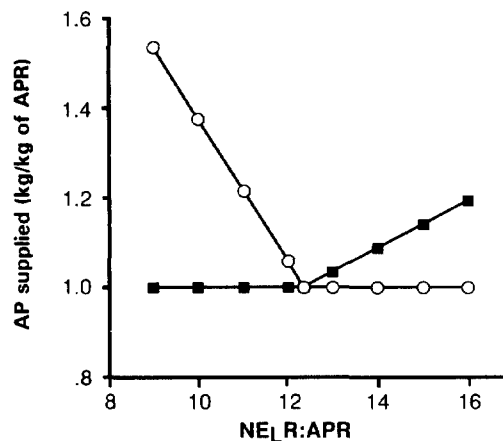


Figure 1. Absorbed true protein (AP) supplied by the diet when AP is limited by rumen-available energy (■) or rumen-available protein (O) for each kilogram of AP required (APR) for different ratios of $NE_L R:APR$ required ($NE_L R:APR$) for marginal production. Shelled corn and soybean meal were used to supply nutrients.

and among farms. Prices for SBM were those paid by producers. Milk prices were those received by producers for all milk adjusted to 3.5% fat. No adjustments of price for protein content of milk were possible because of lack of protein testing and payment during reference years; the average protein content of milk sold during this time was assumed to be 3.2%. Sensitivity of feed costs to changes in feed: milk price ratios was determined to estimate cost rankings among the components for atypical relationships in future years. Ratios analyzed were ± 1.64 standard deviations from their mean ratio.

Relative economic weights for protein:fat were determined to examine the effect of incorporating feed costs into selection indexes on genetic gain for protein relative to fat. Weights were calculated as the ratio of economic value per genetic standard deviation for milk protein to economic value per genetic standard deviation for milk fat using various component prices. Milk protein and fat market values were expressed in terms of kilograms of standard milk (3.5% fat, 3.2% protein) that had the same value as each kilogram of component and ranged from 5 to 25 kg. For example, 5 and 25 kg are equivalent to component prices of \$1.40 and \$7.00/kg, respectively, under a

standard milk price of \$.28/kg. Use of standard milk units enabled comparison of component prices on the same basis as those used for feed costs without defining a specific milk price. Economic weights were determined using both gross and net (gross minus feed costs) component values. Equivalence of gross and net value weights was examined.

RESULTS AND DISCUSSION

Nutrient Requirements

The assumption that requirements for marginal production because of genetic merit must be met completely by increases in nutrient consumption is justified for two reasons. First, several workers found no relationship between breeding value and ration digestibility (18, 19) or between efficiency of energy and protein utilization (10, 12). Second, Bauman et al. (5) summarized literature pertaining to efficiency parameters and concluded that little variability exists for digestibility, metabolizability, or maintenance requirements among cows with different genetic merit for milk production. They suggested that partitioning of absorbed nutrients between the mammary gland and body stores differs greatly; animals of higher genetic merit partition greater amounts of nutrients toward lactation. In addition, animals with high merit convert greater amounts of body stores to milk during early lactation. Because animals must return nutrient body stores to those levels present before lactation commenced, increases in apparent net efficiency above maintenance that were due to tissue mobilization in early lactation must be countered completely by apparent inefficiencies from replenishment of tissue reserves in later lactation.

The $NE_L R$ and APR for marginal production of milk lactose, fat, and protein are presented in Table 1. Fat requires the largest quantity of NE_L ; protein requires the largest quantity of AP. Both fat and lactose require only a small quantity of AP; however, protein requires a substantial amount of NE_L .

Feed Requirements

Quantities of SC and SBM needed to meet nutrient requirements for each milk component vary, depending on whether $NE_L R$:APR for

the sum of all marginal lactation requirements is <12.36 or >12.36 (Table 2). Negative values result from use of simultaneous equations when both marginal energy and protein requirements are met exactly and indicate amounts of a feedstuff that can be removed from the base diet for a cost savings. Required amounts of SC decreased, and SBM increased, as requirements for AP increased across milk components because of higher concentrations of AP in SBM. Lactose and fat had positive requirements for SC and negative requirements for SBM, reflecting their large ratio of $NE_L R$:APR. Milk protein required positive amounts of SBM and negative or slightly positive SC amounts. If each component was produced independently of the others (i.e., marginal production of the other two components equals zero), quantities of SC and SBM that are required would be determined by the $NE_L R$:APR of the component of interest (Table 1).

An alternative approach to solving for amounts of feedstuffs required is formulation of least cost rations by linear programming (24), which would likely reduce estimates of feed cost. However, this approach would require a far more complex model that includes an estimate of marginal intake for each component. More than two feedstuffs could be utilized, but output could fluctuate greatly over time as different feedstuffs served as cheapest sources of NE_L and AP. In addition, AP content and cost of additional feedstuffs would be difficult to determine.

Feed Costs

Ratios of feed:milk price and regression of feed prices on milk price were used to analyze

TABLE 1. Dietary NE_L requirements ($NE_L R$) and absorbed true protein requirements (APR) per kilogram of marginal production of milk components because of genetic merit.

Component	$NE_L R^1$ (Mcal)	APR ² (kg)	$NE_L R$: APR
Lactose	3.95	.14	29.0
Fat	9.23	.13	72.7
Protein	5.71	1.07	5.3

¹From Mertens and Dado (24).

²From Dado et al. (11).

TABLE 2. Quantities of shelled corn (SC) and soybean meal (SBM) needed to meet NE_L requirements (NE_LR) and absorbed true protein requirements (APR) for each kilogram of marginal production of milk components.

NE _L R:APR ¹ (Mcal/kg)	Lactose		Fat		Protein	
	SC	SBM	SC	SBM	SC	SBM
(kg of DM)						
<12.36 ²	3.31	-1.31	9.65	-5.00	-3.98 ³	6.96 ³
≥12.36	2.09 ³	-.07 ³	5.52 ³	-.82 ³	.06	2.88

¹Ratio of the sum of all marginal lactation requirements.

²An NE_LR:APR ratio of 12.36 is the point of optimal utilization of both rumen-available energy and protein for rumen microbial protein synthesis (MPS) when SC and SBM are used to supply nutrients. Below 12.36, MPS is limited by rumen-available energy; above 12.36, MPS is limited by rumen-available protein.

³Feed amount if each component is produced independently of the others (i.e., marginal production of other components equals zero).

feed costs for milk production (Table 3). The 1973 and 1974 data were omitted because the ratios of SC:milk price were >25% above the next highest year. Also, the ratio of SBM:SC price in 1973 was almost 50% higher than the next highest year. Mean price ratios for the remaining 23 yr were all close to their median ratios. Ranges of price ratios were considerable; highest ratios were about twice as high as the lowest ratios. Nevertheless, interquartile ranges of the ratios were near 1 standard deviation, which is somewhat narrower than that for the normal distribution (interquartile range = 1.35 SD). Correlations of prices were high ($r > .85$), indicating that over time prices have moved together. Regression of the ratio of feed:milk price on year resulted in slope coefficients near -.008, indicating that ratios are decreasing by <1.5%/yr from their current

mean. Stability of these historic ratios justifies their use to estimate feed prices in future years. Use of ratios of feed:milk price assumes that inflation rates for feed and milk are equal.

Regression coefficients for feed prices on milk price were similar to, but slightly less than, their corresponding mean ratios. Intercept terms were near zero, indicating that ratios of dependent to independent variables were stable over a wide range of prices. For simplicity, we chose to analyze feed prices by the ratio approach rather than regression. In addition, the ratio approach provided a relationship of SBM and SC prices that was more consistent with the observed prices than was the regression approach. The ratio of the regression coefficient of SBM on milk price to the regression coefficient of SC on milk price was 2.8, which is considerably above the observed coefficient

TABLE 3. Relationships among prices for milk, shelled corn (SC), and soybean meal (SBM) from 1964 to 1988.¹

Ratios ²	\bar{X}	SD	r	Interquartile range	Range
SC:Milk	.54	.11		.47-.59	.30-.74
SBM:Milk	1.23	.14		1.13-1.28	.93-1.53
SBM:SC	2.33	.42		2.03-2.44	1.61-3.51
Regression equation					
SC = .024 + .398 milk			.86		
SBM = .020 + 1.112 milk			.95		
SBM = .009 + 2.247 SC			.89		

¹The 1973 and 1974 data were omitted for which price ratios were .904 and .911 for SC:milk, 2.28 and 1.43 for SBM:milk, and 2.53 and 1.57 for SBM:SC.

²Milk price in dollars per kilogram of milk with 3.5% fat and 3.2% protein and SC and SBM in dollars per kilogram of DM.

TABLE 4. Feed costs for NE_L, absorbed true protein (AP), and milk components expressed as kilograms of milk with 3.5% fat and 3.2% protein.

NE _L R:APR ¹	NE _L	AP	Lactose	Fat	Protein
(Mcal/kg)	(kg/Mcal)		(kg/kg)		
<12.36 ²	-.201	6.954	.152	-.971	6.288 ³
≥12.36	.172	2.342	.999 ³	1.887 ³	3.487

¹The NE_L required:AP required for the sum of all marginal lactation requirements. Assumes shelled corn:milk price ratio = .52 and soybean meal:milk price ratio = 1.20.

²An NE_LR:APR ratio of 12.36 is the point of optimal utilization of both rumen-available energy and protein for rumen microbial protein synthesis (MPS) when SC and SBM are used to supply nutrients. Below 12.36, MPS is limited by rumen-available energy; above 12.36, MPS is limited by rumen-available protein.

³Feed cost if each component is produced independently of the others (i.e., marginal production of other components equals zero).

of 2.2. Ratios of .52 and 1.20 for SC:milk price and SBM:milk price, respectively, were used to simplify subsequent calculations.

A long-term view of prices is preferred over the use of temporally localized prices that fluctuate with markets when feed costs are estimated for use in selection models because of the extended, continuous nature of selection and because selection decisions for dairy cattle precede economic responses by several years. In addition, a price model for feeds was sought that was resistant to inflation. Previous workers (13, 16, 20, 21) have simply assigned a constant cost to dietary energy. These static feed costs are useful for only short periods and may reflect unusual short-term relationships of feed and milk prices. The relatively stable relationships of feed:milk price over the long term can be usefully applied to selection models. Although these results are applicable to the US economy, similar procedures could be used to derive feed costs for other economies when price relationships are reasonably stable over time.

Feed costs for NE_L, AP, and each milk component, expressed as kilograms of standardized milk with equivalent value, are presented in Table 4. Actual costs depend on the NE_LR:APR for the sum of all marginal lactation requirements. Below an NE_LR:APR ratio of 12.36, NE_L cost was negative because additional energy contributes to MPS and AP production. Cost for AP was greater when NE_LR:APR <12.36 because rumen-available protein, which is more expensive than rumen-available energy, was overfed. Combined NE_L

and AP costs were lowest when NE_LR:APR = 12.36. A negative cost for NE_L suggests that the model for feed cost using only SC and SBM may be unrealistic when NE_LR:APR is <12.36. Constant ratios of rumen-degradable protein:RUP are assumed, so degradable protein is greatly overfed when NE_LR:APR is low. Producers typically would increase RUP concentrations in the diet; however, the cost of RUP is difficult to determine.

Analysis of breeding values for AI sires proven in 1992 revealed that >95% have marginal NE_LR:APR ratios >12.36 based on PTA for lactose, fat, and protein (data not shown). Therefore, component costs under most situations are 1.00, 1.89, and 3.49 kg of standard milk/kg of lactose, fat, and protein, respec-

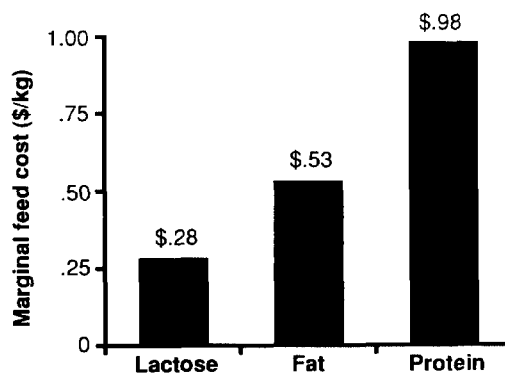


Figure 2. Feed cost for marginal production of each milk component expressed in dollars per kilogram under a standard milk (3.5% fat and 3.2% protein) price of \$.28/kg.

tively (Table 4); these costs are used for the remainder of this discussion. Component feed costs under a standard milk price of \$.28/kg are expressed in dollars per kilogram in Figure 2. Under this scenario, feed cost per unit of milk fat is 1.9 times that for lactose, and cost per unit of milk protein is 1.8 times that for fat. Meeting only dietary energy requirements for each component results in highest feed costs for fat, then protein, and finally lactose (13, 15, 20), and these values are supported by NE_L requirements in Table 1.

Feed costs for lactose and fat were relatively insensitive to changes in the ratio of SBM:milk price but were more sensitive to changes in the ratio of SC:milk price (Table 5). Conversely, feed costs for milk protein were insensitive to ratio of SC:milk price and sensitive to ratio of SBM:milk price. Feed costs declined for lactose and fat as the ratio of SBM:milk price increased because of negative amounts of SBM required for lactose and fat production. Nonetheless, at all combinations of feed:milk price, except when SC:milk price was highest and SBM:milk price was lowest, milk fat remained more costly than lactose, and protein remained more costly than fat. If future price ratios deviate far from their mean ratios, both ratios would likely change in similar directions, which is supported by the positive correlation ($r = .55$) between ratios of SC:milk price and SBM:milk price for previous years. Beard (6) calculated economic weights for use in merit equations and found that they were sensitive to feed price. Weights for fat

and protein moved in similar directions as feed price increased because energy was the only requirement used to calculate feed costs.

Total feed cost for marginal production depends not only on the transmitted yields for each component but also on the NE_L :APR for the sum of all marginal lactation requirements. Milk components are less costly to produce when their overall NE_L :APR is close to 12.36, which is achieved only when more than one component is selected. For example, increased selection for milk fat results in lower total feed costs if selected with milk protein when the marginal NE_L :APR is below 12.36 (Figure 3). Genetic standard deviations were 40 kg for lactose, 32 kg for fat, and 29 kg for protein as calculated from equations of Van Vleck and Dong (29). Selection and marginal production of only one component result in NE_L :APR ratios some distance from that for optimal MPS and cause MPS to be more inefficient. Interrelationships among ruminal energy and protein may help to explain why correlated responses exist between milk fat and protein (16) and may lead to nutritional challenges during attempts to alter milk composition permanently through genetic manipulation (8, 15).

Application of Feed Cost Model to Selection Indexes

With feed cost estimates for individual milk components, selection indexes based on net returns above feed costs may be calculated for

TABLE 5. Feed cost per kilogram of milk component with various shelled corn (SC):milk price and soybean meal (SBM):milk price ratios.¹

Component	SC:Milk price	SBM:Milk price		
		.97	1.20	1.43
Lactose	.34	.64	.62	.61
	.52	1.02	1.00	.98
	.70	1.39	1.37	1.36
Fat	.34	1.08	.89	.71
	.52	2.08	1.89	1.70
	.70	3.07	2.88	2.69
Protein	.34	2.81	3.48	4.14
	.52	2.83	3.49	4.15
	.70	2.84	3.50	4.16

¹Feed cost is expressed as kilograms of milk with 3.5% fat and 3.2% protein with equivalent value. The NE_L :absorbed protein requirement ratio for the sum of all marginal lactation requirements was assumed to be >12.36.

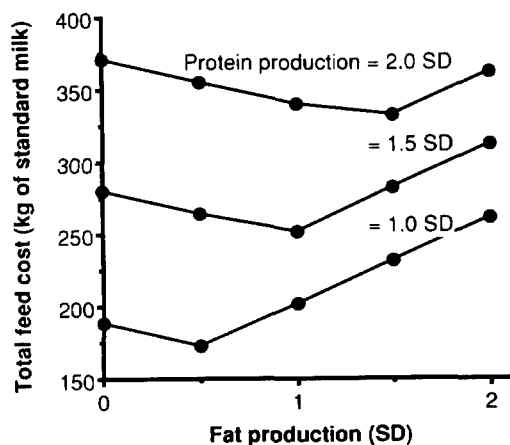


Figure 3. Total marginal feed cost from milk component selection expressed as kilograms of milk with 3.5% fat and 3.2% protein for various productions of milk fat and protein (in units of genetic standard deviation) with lactose selection held at a constant increase of 1 standard deviation. $NE_L R:APR = NE_L$ Requirements:absorbed true protein requirements for the sum of all marginal lactation requirements.

production in the US. The $PTA_{\$P}$ index (27) can be modified accordingly:

$$PTA_{\$P}^* = [PTA_m \times (MP_m - FC_m)] + [PTA_f \times (MP_f - FC_f)] + [PTA_p \times (MP_p - FC_p)] \quad [6]$$

where $PTA_{\$P}^*$ is predicted marginal income

over feed cost; PTA_m , PTA_f , and PTA_p are PTA in kilograms per lactation for milk, fat, and protein, respectively; MP_m , MP_f , and MP_p are market prices per kilogram of milk (fat- and protein-free), fat, and protein, respectively; and FC_m , FC_f , and FC_p are feed costs per kilogram of milk (fat- and protein-free), fat, and protein, respectively. Because feed costs were expressed in terms of kilograms of standard milk with equivalent value, dollar costs for feed are calculated by multiplication of the current milk price (dollars per kilogram of 3.5% fat and 3.2% protein milk) by 1.00, 1.89, and 3.49 kg of standard milk/kg of lactose, fat, and protein, respectively. Genetic correlations between milk production and lactose-mineral production are high and positive for all breeds, reflecting small variations in concentration of these components in milk (32). Therefore, feed costs associated with PTA_m were assumed to be due to lactose production, where $FC_m = 1.00$ kg of standard milk/kg of lactose \times dollars per kilogram of standard milk \times .048 kg of lactose/kg of milk.

Relative economic weights for protein:fat are presented in Table 6 for both gross value and net value indexes. The gross value index uses market prices to weight each trait, and the net value index uses market prices minus feed cost. Values near 1.0 indicate that a 1-genetic standard deviation quantity of milk protein and fat have equivalent value. Although efficiency of selection may not change appreciably from changes in weights (17), the impact on selec-

TABLE 6. Relative economic weights for milk protein:milk fat based on gross value or net value indexes.¹

	Milk protein price ²	Milk fat price ²		
		5	15	25
Gross value index	5	.91	.30	.18
	15	2.72	.91	.54
	25	4.53	1.51	.91
Net value index	5	.44	.10	.06
	15	3.35	.80	.45
	25	6.26	1.49	.84
Ratio of net value: gross value	5	.49	.35	.33
	15	1.23	.88	.83
	25	1.38	.98	.93

¹Net value index assumes that shelled corn:milk price ratio = .52 and soybean meal:milk price ratio = 1.20. The NE_L :absorbed protein requirement ratio for the sum of all marginal lactation requirements was assumed to be >12.36.

²Value of component in terms of kilograms of standard milk (3.5% fat, 3.2% protein) that has the same value as each kilogram of protein or fat.

tion response when gross value index is changed to a net value index may be evaluated as the ratio of relative weights based on net value to relative weights based on gross value. Values near 1 suggest that both relative weights are similar and that both indexes produce similar rates of genetic gain. Relative economic weights for protein:fat were lower for net value than for gross value indexes for most price scenarios, suggesting that the rate of gain for protein:fat production would be less with the net value index than with the gross value index. Only when protein price was medium or high and fat price was low did the net index result in larger relative weights for protein:fat. Under these circumstances, genetic gain for protein production relative to fat would be greater for the net index. Future prices for fat and protein may reach these levels if consumers continue to decrease consumption of milk fat.

CONCLUSIONS

Dietary energy and protein relationships were evaluated to calculate feed amounts required to provide NE_L and AP for marginal production of milk components that were due to genetic merit. Ratios of feed:milk price from 1964 to 1988 were stable over time and provided useful estimates of feed costs as milk prices change over time in the US. Average price ratios for SC:milk and SBM:milk were .52 and 1.20, respectively. Using SC and SBM, feed costs per kilogram of fat were 1.9 times that for lactose; costs for milk protein were 3.5 times that for lactose and 1.8 times that for fat. Milk protein costs were higher when MPS was limited by rumen-available energy, suggesting that selection for fat or lactose, in addition to protein, may be beneficial. Use of a net value index would reduce selection emphasis on protein relative to fat under most prices examined. Only when fat price is low and protein price is high is relative emphasis for protein:fat higher for a net return index than for a gross return index.

Results suggest that adequate prices must be offered for milk protein to offset the high feed cost of producing and selecting for protein. In addition, nutrition research should continue to seek low cost sources of dietary protein and methods to increase feed protein that

escapes rumen degradation. Accounting for differences in feed cost for components is necessary for selection indexes that seek to maximize genetic gain for net return.

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